RF LOSSES IN SUPERCONDUCTING LEAD CAVITIES*

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At the present time the only materials seriously considered for superconducting accelerators are lead and niobium. In the electron linacs under construction at Stanford[1] and the University of Illinois[2] cylindrical niobium cavities are being employed. The relatively uncomplicated geometry of such cavities permits the fabrication and annealing procedure to be approached in a straightforward (though expensive and time-consuming) manner and offers the optimum final energy gradient for these accelerators.[3] However, the complicated geometrical structures (e.g., drift tubes or helically loaded wave guides) required for low phase velocity heavy-ion accelerators make the use of niobium less appealing. In contrast, lead may be easily plated on even very complicated structures with a minimum degree of difficulty and cost.

Tests on a prototype accelerator at Stanford have demonstrated, however, that the RF losses in lead cavities are significantly larger than can be explained from the normal losses in the superconducting surface.[4] There is, therefore, some interest in identifying the source of these "residual" losses as the first hopeful step toward their removal.

Measurements at Caltech by G. J. Dick in 100 MHz helically loaded cavities have shown that these residual losses may be due to a thin dielectric layer on the surface of the superconductor.[5] Considering just the RF losses in the superconductor itself, it should be possible to attain a maximum Q of about 10^9 in these cavities. However, Q's of only 2×10^8 have been reached indicating that a layer of PbO about 250 Å thick would be necessary to explain the observed losses.

The actual composition of the surface layer is not understood, but it can be quite reasonably assumed that if one is present it will contain oxygen -- whether in the form of an oxide, hydroxide, carbonate or hydrated compound. For this reason we have determined the ^{16}O concentration on samples cut from the lead cavities used in the RF measurements.[5] Since the amount of oxygen present was expected to be small, we chose a nuclear reaction that is quite specific for ^{16}O, and which has no contribution from the lead (or other materials) present.

The strongly exothermic reaction $^{16}O(^3He,\alpha)^{15}O$ was chosen because the emerging alpha particles have a sufficiently high energy that they can be easily distinguished from the intense flux of elastically scattered ^3He's. The experiment was performed in the following manner: The sample was placed in an evacuated scattering chamber and bombarded with 2-3 MeV $^3He^+$ ions from the ONR-CIT tandem accelerator. The alpha particles from the $^{16}O(^3He,\alpha)^{15}O$ reaction were detected at 90° to the incoming beam with a silicon surface-barrier detector. Immediately, in front of the detector was a 3/4 mil aluminum foil that prevented any scattered ^3He's from reaching the detector; the alpha particles had enough energy to pass through the absorber into the detector.

The yield of alpha particles versus ^3He bombarding energy clearly showed the 0.2-MeV wide resonance at $E_{^3He}$ = 2.36 MeV studied previously by Silverstein, et al.[6] and Bromley, et al.[7] Using Silverstein's values of the reaction cross section, the ^{16}O concentrations shown in Table 1 were obtained. Since the layer is extremely thin, our measurements only determine the concentration per unit area -- a depth can be determined only if the composition is known. Assuming that the oxygen was present in the form of a uniform layer of PbO, the thicknesses given in Table 1 were calculated.

We used the same procedure on two different samples of aluminum foil and obtained thicknesses of 48 and 114 Å. This is consistent with the known oxide layer on clean aluminum surfaces,[8] giving a general check on the accuracy of our results. The following precautions were also taken:

(1) To make sure that the samples were uniform several spots on each target were measured -- all agreed to within the accuracy of the individual measurements.

(2) To insure that we were not driving off the oxygen in the surface layer under prolonged bombardment, we ran fresh spots on the target with much lower beam intensity -- again the agreement between the various spots on a given target was excellent.

Table 1

^{16}O Surface Concentrations Determined for Various Materials using the $^{16}O(^3He,\alpha)^{15}O$ Reaction

Sample	Age (days)	^{16}O Concentration (atoms/cm^2)	Thickness* (Å)
Plated lead	~ 5	2.7×10^{16}	104 ± 16
Lead cavity ($Q = 4\times10^5$)	30	3.4×10^{16}	139 ± 21
Lead cavity ($Q = 5\times10^7$)	2	2.8×10^{16}	110 ± 25
Lead cavity ($Q = 6\times10^7$)	30	2.4×10^{16}	95 ± 23
Aluminum foil	--	2.7×10^{16}	114 ± 6
Aluminum foil	1	1.1×10^{16}	48 ± 3
Anodized lead	--		$(7\pm1)\times10^3$

*The thicknesses shown assume a uniform layer of PbO for the lead samples and Al_2O_3 for the aluminum samples.

Our results indicate that all the samples from the lead cavities had a surface ^{16}O concentration that would correspond to a PbO thickness of about 100 Å. The samples had been carefully stored to avoid exposure to normal atmospheric humidity; our results show that oxidation from this source was small because no correlation of ^{16}O concentration with age was seen. The thicknesses measured are much too small to explain the magnitude of the losses and do not explain the variation in the observed Q's. It cannot, however, be excluded that for a cavity with a Q of 2×10^8 the dielectric losses in a

*Supported in part by the National Science Foundation (GP-9114 and GP-19887).

100 Å layer might be the limiting factor -- considering the uncertainty in dielectric loss angles for such materials at low temperature.

We have made calculations which show that the local enhancement of the electric field due to microscopic surface roughness does not change our conclusions about the magnitude of the dielectric losses. The increase in surface area from roughness does, however, increase the normal RF losses in the superconductor since the penetration depth is smaller than the surface structures observed.[9] The normal RF losses are in this case within a factor of 2-3 of explaining the losses in a cavity with $Q = 2 \times 10^8$.

The authors would like to acknowledge helpful conversations with G. J. Dick, K. W. Shepard, A. J. Sierk, and W. R. Smythe.

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